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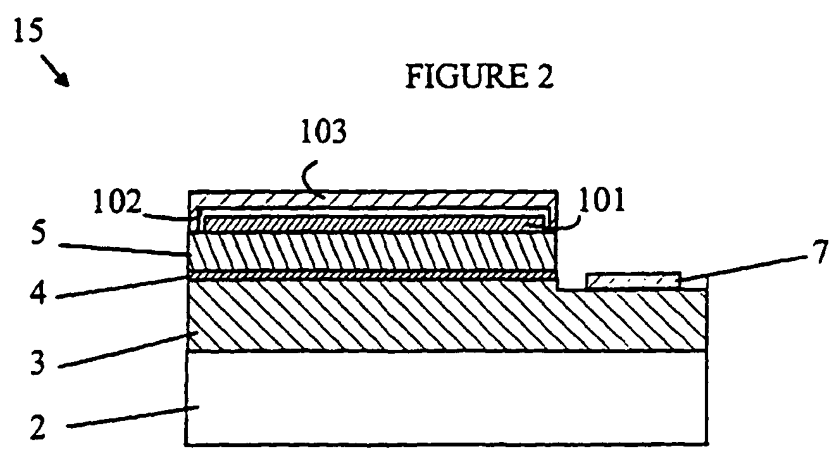
(54) **Light emitting device**

(57) A light emitting device [10, 15, 50, 130] is constructed on a substrate [2, 132]. The device includes an n-type semiconductor layer [3] in contact with the substrate [2, 132], an active layer [4] for generating light, the active layer [4] being in electrical contact with the n-type semiconductor layer [3]. A p-type semiconductor layer [5] is in electrical contact with the active layer [4], and a p-electrode [21, 51, 101] is in electrical contact with the p-type semiconductor layer [5]. The p-electrode [21, 51, 101] includes a layer of silver in contact with the p-type semiconductor layer [5]. In the preferred embodiment of the present invention, the n-type semiconductor layer [3] and the p-type semiconductor layer [5] are constructed from group III nitride semiconductor materials. In one embodiment of the invention the silver layer is sufficiently thin to be transparent. In other embodiments, the silver layer is thick enough to reflect most of the light incident thereon. A fixation layer [52, 102] is preferably provided over the silver layer. The fixation layer [52, 102] may be a dielectric or a conductor, the choice depending on whether or not the silver layer is transparent.

FIGURE 2



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Figures 3(A)-(C) are cross-sectional views of an LED and package before and after mounting the LED on the package.

Figure 4 is a cross-sectional view of another embodiment of LED.

[0015] The preferred embodiment achieves its advantages by utilizing a silver-based p-electrode. An LED according to the preferred embodiment can be constructed with either a reflective p-electrode and a transparent substrate or a transparent p-electrode and a reflective substrate. Embodiments of the present invention utilizing a reflective p-electrode will be described first.

[0016] The light generated in the active region of the LED exits the LED through the substrate when a reflective p-electrode is utilized. Light exiting the active region in the direction of the p-electrode is reflected back towards the substrate by the reflective p-electrode. The p-electrode utilizes silver as the first metal layer in at least a part of the p-electrode. In an optoelectronic device, a silver layer is vapor-deposited on the p-type nitride semiconductor layer and functions as the p-electrode and as a mirror for reflecting light back toward the transparent substrate.

[0017] Referring now to Figure 1, which is a cross-sectional view of a first embodiment of LED, LED 10 is constructed on a sapphire substrate 2 by depositing an n-layer 3, an active layer 4 that is usually a multi-quantum well layer of a nitride semiconductor, and a player 5. This series of layers is essentially that deposited in constructing a conventional LED up to the point of providing the p-electrode. LED 10 utilizes a silver (Ag) layer 21 as the first metal layer of the p-electrode. A second metal layer for bonding the p-lead wire 6 is constructed from nickel and gold and shown at 21A. An n-electrode 7 is also provided in the conventional manner together with a bonding pad for connecting the n-lead wire 7A.

[0018] The method by which LED 10 is fabricated will now be explained in more detail. First, conventional processes such as CVD are used to successively form n-layer 3, active layer 4, and p-layer 5 on a sapphire substrate 2. Next, the LED is patterned photolithographically using nickel as the mask and is etched back into n-layer 3 to form the pad for n-electrode 7 by reactive ion etching. The nickel mask is then removed by applying aqua regia at room temperature.

[0019] The removal of the mask via aqua regia also cleans the surface of p-layer 5, and hence, aqua regia is preferred to other etchants for removing the nickel mask. The part is left in the aqua regia for 30 minutes to one hour. If the etching time is less than 30 minutes, the cleaning of the p-layer surface is insufficient, even though the nickel mask has been removed. Insufficient cleaning leads to a loss in the stability of the silver that is vapor-deposited on p-surface in the subsequent deposition steps. Hence, reducing the immersion time significantly below 30 minutes must be avoided.

[0020] Next, the LED part is activated for five minutes with sapphire substrate 2 at 900°C in a nitrogen atmosphere. After the activation, the LED part is cleaned in hydrofluoric acid for 10 minutes at room temperature. A 100 nm layer of Ag is then vapor-deposited on p-layer 5 to form the first layer 21 of the p-electrode. It should be noted that the reflectance of the Ag layer does not improve substantially if the thickness is increased above 100 nm.

[0021] Next, about 300 nm of nickel and 50 nm of gold are successively vapour deposited and patterned to form electrode metal layer 21 A for bonding to the p electrode and a first annealing is performed (annealing 1).

[0022] Next, 10 nm of Ti and 200 nm of Al are successively vapor-deposited and patterned on the n-type GaN part to form n-electrode 7. A second annealing operation is then performed. The LED may then be separated from the other devices, such as other LEDs, formed on the same wafer. The LED is then mounted in a suitable package (not shown), the p-lead wile 6 is connected between the electrode metal layer 21A and a first bond pad (not shown) that forms part of the package, and the n-lead wire 7A is connected between the n-electrode 7 and a second bond pad (not shown) that forms part of the package. The LED is oriented in the package in a direction that allows light transmitted through the substrate 2 to be radiated from the package.

[0023] It should be noted that annealing 1 can be omitted. Annealing 1 is performed at or below 200 °C, and annealing 2 is performed above 200°C, preferably above 400°C. The annealing operations are found experimentally to reduce the resistance of the p-contact.

[0024] The characteristics of an LED according to the present invention depend on the speed with which the silver is deposited and on the temperature of the sapphire substrate during the vapor deposition. It has been found experimentally that the preferred deposition conditions are a vapor deposition speed of approximately 0.05 nm/second or less and a temperature of the sapphire substrate 2 of 200°C or less. At temperatures of 400°C, the silver layer becomes non-uniform, and the resistance of the silver layer increases. As noted above, the resistance of the p-electrode is a significant factor in the overall efficiency of the LED, and hence, such increases in resistance are to be avoided.

[0025] The silver-based p-electrode of the present invention is particularly well suited for reflective electrodes in the blue to green region of the spectrum. While palladium, platinum, nickel, gold, aluminum, chromium, and titanium layers could be utilized to create a reflective electrode, silver has a substantially higher reflectance than the other candidates. In addition, silver, unlike gold, aluminium, chrome, and titanium, forms an ohmic junction at the p-type GaN.

[0026] The portions of the silver layer that are not covered by the mounting pad 21A are preferably covered by

independent of the thickness of the silver layer and is approximated by 25λ/450, where λ is the wavelength (in nm) of the generated light.

[0038] TiO_2 layer 52 is preferably deposited by vapor-deposition. When TiO_2 layer 52 is used, the conditions under which silver layer 51 is deposited are less critical than described above with respect to LED 10 shown in Figure 1. In particular, the vapor deposition speed of silver can be increased.

[0039] It should be noted that other dielectric films may be used in place of TiO_2. For example, layer 52 may be constructed from SiO_2 or Al_2O_3.

[0040] In the preferred embodiment of the present invention, either the boundary of substrate package 8 and substrate 2 or the boundary of substrate 2 and n-layer 3 is reflective for light of the wavelength generated in active layer 4. Such a reflective layer assures that light leaving active layer 4 toward substrate 2 is reflected back toward the transparent p-electrode.

[0041] The above-described embodiments of the present invention have utilized a sapphire substrate. However, it will be obvious to those skilled in the art from the preceding discussion that other substrates may be utilized. In addition, the substrate may include one or more buffer layers, the n-type semiconductor layer being deposited on the last of these buffer layers. Accordingly, it is to be understood that the term "substrate" includes such buffer layers.

[0042] Similarly, the above-described embodiments of the present invention have been described in terms of a p-type semiconductor layer and an n-type semiconductor layer that sandwich an active layer that generates light when a potential is applied across the semiconducting layers. However, it will be evident to those skilled in the art from the preceding discussion that each of these layers may include a number of sub-layers. Accordingly, it is to be understood that the term "layer" as used herein includes multi-layered structures.

[0043] Various modifications to the present invention will become apparent to those skilled in the art from the foregoing description and accompanying drawings. Accordingly, the present invention is to be limited solely by the scope of the following claims.

[0044] The disclosures in Japanese patent application nos. 9-345584 and 9-345985, from which this application claims priority, and in the abstract accompanying this application are incorporated herein by reference.

Claims

1. A light emitting device comprising: a substrate [2, 132]; an n-type semiconductor layer [3] in contact with said substrate [2, 132]; an active layer [4] for generating light, said active layer [4] being in electrical contact with said n-type semiconducting layer; a p-type semiconductor layer [5] in electrical contact with said active layer [4]: and a p-electrode [21, 51, 101] in electrical contact with said p-type semiconductor layer [5], said p-electrode [21, 51, 101] comprising a layer of silver in contact with said p-type semiconductor layer [5].

2. A light emitting device as in claim 1, wherein said n-type semiconductor layer [3] and said p-type semiconductor layer [5] comprise group III nitride semiconducting materials.

3. A light emitting device as in claim 1 or 2, wherein said silver layer is greater than or equal to 20 nm in thickness.

4. The light emitting device as in claim 3, wherein said p-electrode [21, 51, 101] comprises a fixation layer [52, 102] in electrical contact with said layer of silver, said fixation layer [52, 102] comprising a metal chosen from the group consisting of nickel, palladium, and platinum: and/or a bonding layer [21A, 51A, 103] in electrical contact with said layer of silver for making electrical connections to said layer of silver and preferably comprising a metal chosen from the group consisting of gold and aluminium.

5. A light emitting device as in claim 4, comprising: an n-electrode [7] comprising a layer of electrically conductive material in electrical contact with said n-type semiconductor layer [3]; and a package [140] including first and second conductors for supplying power to said p-electrode [21, 51, 101] and said n-electrode [7], respectively.

6. A light emitting device as in claim 5, comprising a metallic bonding layer [21A, 51A, 103] between said first conductor and said p-electrode [21, 51, 101] preferably comprising indium.

7. A light emitting device as in claim 1, wherein said layer of silver is less than 20 nm in thickness.

8. A light emitting device as in claim 7, wherein said p-electrode [21, 51, 101] comprises a fixation layer [52, 102] in contact with said layer of silver, said fixation layer[52, 102] comprising a compound chosen from the group consisting of TiO_2, SiO_2, and Al_2O_3; and/or a bonding layer [21A, 51A, 103] comprising a metal chosen from the group consisting of gold and aluminum, said bonding layer [21A, 51A, 103] being in electrical contact with said layer of silver, said bonding layer [21A, 51A, 103] covering less than half of said layer of silver.

9. A method of fabricating a light emitting device comprising the steps of: generating an n-type semiconductor layer [3] on a substrate [2, 132]; generating an active layer [4] on said n-type semiconductor layer [3], said active layer [4] generating light by the recombination of holes and electrons therein; gen-

FIGURE 1

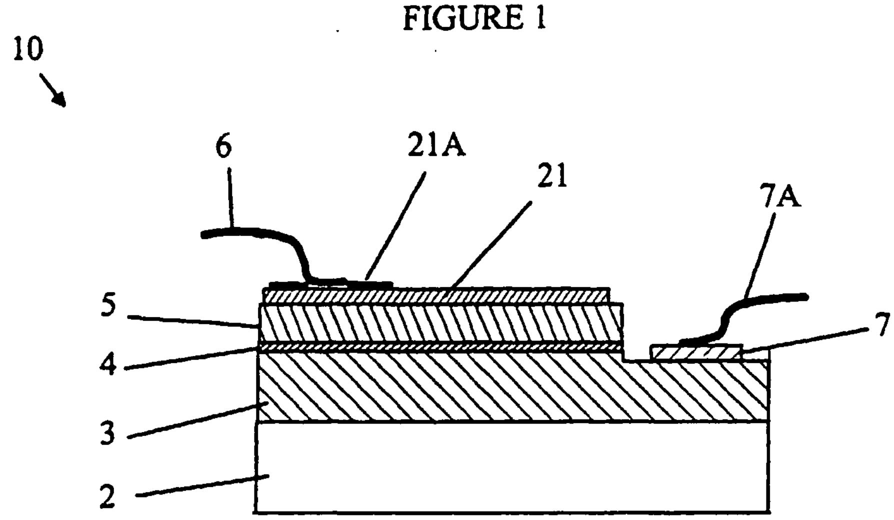
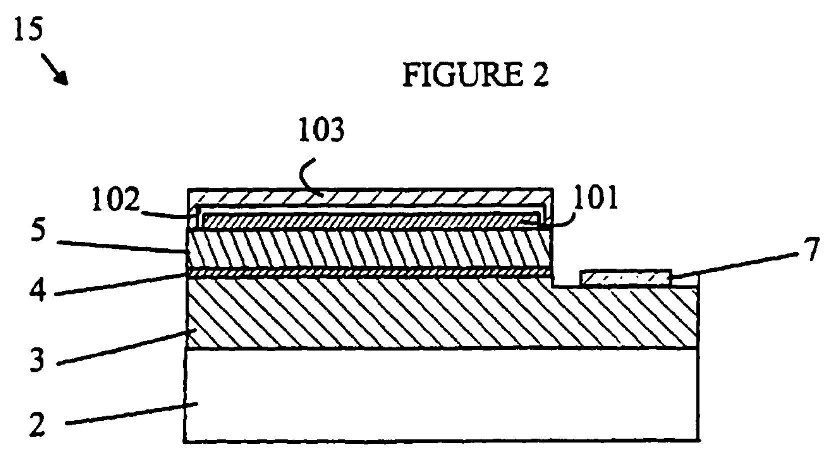


FIGURE 2



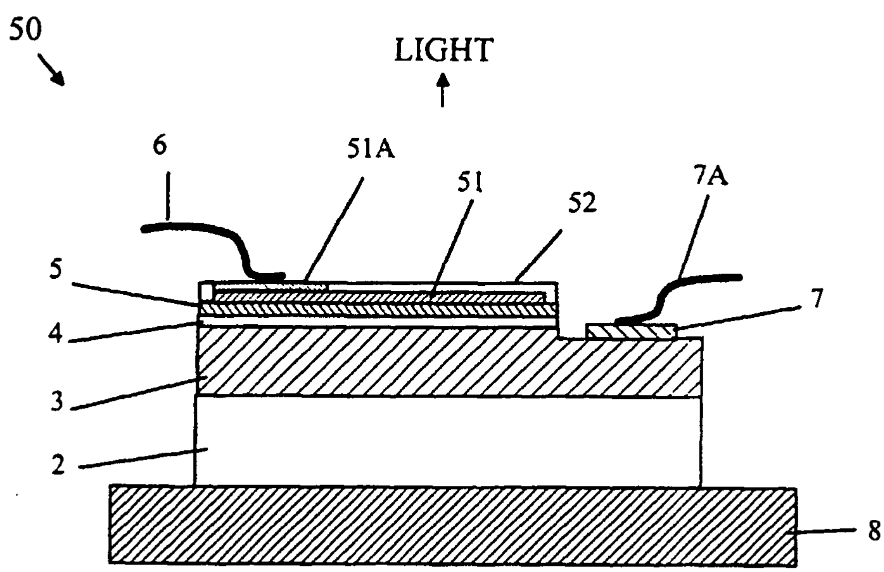


FIGURE 4